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# TITLE OF THE INVENTION

## QoS-based Shortest Path Routing for a Hierarchical Communication Network

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates generally to communications networks, and more specifically to an on-demand QoS (quality-of-service)-based routing for a hierarchical communication network.

### Description of the Related Art

RFC (Request for Comments) 2328 and 2676 texts describe a hierarchical communication network in which QoS-based on-demand routing is performed using the OSPF (Open Shortest Path First) algorithm, known as QOSPF (QoS extended OSPF). On-demand QoS routing algorithm is one that determines a QoS route to a user-specified destination using the Dijkstra algorithm. This QoS routing is particularly useful for QoS-guaranteed networks such as multi-protocol label switching (MPLS) networks. The hierarchical communication network is comprised of a plurality of routers interconnected by links. Each of the routers belongs to one of a plurality of areas, one of which is the backbone area which is traversed by traffic between non-adjacent areas. Adjacent areas are interconnected by at least one router known as an area border router (ABR). If an area border router receives an on-demand QoS route calculation request from a user, requesting a route to a destination that is located in one of its neighboring areas, the router calculates a QoS-based shortest path tree (SPT) according to the Dijkstra algorithm. However, since the router has no knowledge of which areas can be traversed

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1 to reach the specified destination, the QoS-SPT calculation must be  
2 performed for all of its neighboring areas. Further, the router has no  
3 knowledge of which remote area border routers can be used as intermediate  
4 routers to reach a remote destination. Therefore, if the destination is in a  
5 remote area and can be reached via the backbone area, the QoS-SPT must be  
6 calculated for all possible routes of the backbone area from the source router  
7 to the remote area border routers, in addition to the QoS-SPT calculations for  
8 all possible routes of the local area of the source router. As a result, the prior  
9 art routing technique is wasteful of QoS-SPT calculations.

## SUMMARY OF THE INVENTION

11 It is therefore an object of the present invention to provide a  
12 hierarchical communication network and a method of communication that  
13 eliminate the wasteful route calculations.

14 Another object of the present invention is to provide QoS-based  
15 routing that allows each router of the network to possess the knowledge of all  
16 areas that can be traversed in advance of selecting links.

17           A further object of the present invention is to provide QoS-based  
18 routing that allows each router of the network to possess, for each traversable  
19 area, the knowledge of all area border routers that can be used as transit  
20 routers to reach a remote destination via the traversable area.

21 According to a first aspect of the present invention, there is provided a  
22 router for a hierarchical communication network which is divided into a  
23 plurality of areas in each of which a plurality of the router are interconnected  
24 by links, comprising a first table having a plurality of entries respectively  
25 corresponding to reachable destinations, each of the entries including an

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1 intra-area or an inter-area indication and an area identifier identifying at least  
2 one traversable area and a plurality of second tables respectively  
3 corresponding to the areas, each of the second tables holding quality-of-  
4 service (QoS) values of the links of the corresponding area. A processor is  
5 responsive to a request signal specifying a destination and a QoS value for  
6 making reference to one of the entries of the first table and one of the second  
7 tables corresponding to the specified destination, selecting links of the area  
8 identified by the area identifier of the referenced entry which links satisfy the  
9 specified QoS value, and performing a calculation according to a shortest  
10 path finding algorithm on the selected links to find a shortest path to the  
11 specified destination if the intra-area indication is included in the referenced  
12 entry, or performing the shortest path calculation on the selected links to find  
13 a shortest path tree in the identified area and determining a route from the  
14 shortest path tree.

15 According to a second aspect, the present invention provides a router  
16 for a hierarchical communication network which is divided into a plurality of  
17 areas in each of which a plurality of the router are interconnected by links,  
18 wherein neighboring ones of the areas are interconnected by at least one area  
19 border router. The router comprises a first table having a plurality of entries  
20 respectively corresponding to reachable destinations, each of the entries  
21 including an intra-area or an inter-area indication, an area identifier  
22 identifying at least one traversable area, and a list of area border routers if the  
23 inter-area indication is included and a plurality of second tables respectively  
24 corresponding to the areas, each of the second tables holding quality-of-  
25 service (QoS) values of the links of the corresponding area. A processor is

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1 responsive to a request signal specifying a destination and a QoS value for  
2 making reference to one of the entries of the first table and one of the second  
3 tables corresponding to the specified destination, selecting links of the area  
4 identified by the area identifier of the referenced entry which links satisfy the  
5 specified QoS value, and performing a calculation according to a shortest  
6 path finding algorithm on the selected links to find a shortest path to the  
7 specified destination if the intra-area indication is included in the referenced  
8 entry, or performing the shortest path calculation on the selected links until a  
9 shortest path tree is found for all routers of the list of the referenced entry or  
10 until an end of the calculation is reached when the tree is not found for all the  
11 routers if the inter-area indication is included in the referenced entry, and  
12 determining from the shortest path tree a route having an optimum QoS  
13 value.

14 According to a third aspect of the present invention, there is provided  
15 a hierarchical communication network which is divided into a plurality of  
16 areas in each of which a plurality of the router are interconnected by links.  
17 Each of the routers comprises a first table having a plurality of entries  
18 respectively corresponding to reachable destinations, each of the entries  
19 including an intra-area or an inter-area indication and an area identifier  
20 identifying at least one traversable area and a plurality of second tables  
21 respectively corresponding to the areas, each of the second tables holding  
22 quality-of-service (QoS) values of the links of the corresponding area. A  
23 processor is responsive to a request signal specifying a destination and a QoS  
24 value for making reference to one of the entries of the first table and one of  
25 the second tables corresponding to the specified destination, selecting links of

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1 the area identified by the area identifier of the referenced entry which links  
2 satisfy the specified QoS value, and performing a calculation according to a  
3 shortest path finding algorithm on the selected links to find a shortest path to  
4 the specified destination if the intra-area indication is included in the  
5 referenced entry, or performing the shortest path calculation on the selected  
6 links to find a shortest path tree in the identified area and determining a  
7 route from the shortest path tree.

8 According to a fourth aspect, the present invention provides a  
9 hierarchical communication network which is divided into a plurality of  
10 areas in each of which a plurality of routers are interconnected by links,  
11 wherein neighboring ones of the areas are interconnected by at least one area  
12 border router. Each of the routers comprises a first table having a plurality of  
13 entries respectively corresponding to reachable destinations, each of the  
14 entries including an intra-area or an inter-area indication, an area identifier  
15 identifying at least one traversable area, and a list of area border routers if the  
16 inter-area indication is included, and a plurality of second tables respectively  
17 corresponding to the areas, each of the second tables holding quality-of-  
18 service (QoS) values of the links of the corresponding area. A processor is  
19 responsive to a request signal specifying a destination and a QoS value for  
20 making reference to one of the entries of the first table and one of the second  
21 tables corresponding to the specified destination, selecting links of the area  
22 identified by the area identifier of the referenced entry which links satisfy the  
23 specified QoS value, and performing a calculation according to a shortest  
24 path finding algorithm on the selected links to find a shortest path to the  
25 specified destination if the intra-area indication is included in the referenced

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1 entry, or performing the shortest path calculation on the selected links until a  
2 shortest path tree is found for all routers of the list of the referenced entry or  
3 until an end of the calculation is reached when the tree is not found for all the  
4 routers if the inter-area indication is included in the referenced entry, and  
5 determining from the shortest path tree a route having an optimum QoS  
6 value.

7 According to a fifth aspect of the present invention, there is provided a  
8 routing method for a hierarchical communication network which is divided  
9 into a plurality of areas in each of which a plurality of the router are  
10 interconnected by links, each of the routers comprising a first table having a  
11 plurality of entries respectively corresponding to reachable destinations, each  
12 of the entries including an intra-area or an inter-area indication and an area  
13 identifier identifying at least one traversable area, and a plurality of second  
14 tables respectively corresponding to the areas, each of the second tables  
15 holding quality-of-service (QoS) values of the links of the corresponding area,  
16 each of the routers functioning as a source router when a request signal is  
17 received. The method comprises the steps of receiving, at the source router, a  
18 request signal specifying a destination and a QoS value and making reference  
19 to one of the entries of the first table and one of the second tables  
20 corresponding to the specified destination, selecting links of the area  
21 identified by the area identifier of the referenced entry which links satisfy the  
22 specified QoS value, and performing a calculation according to a shortest  
23 path finding algorithm on the selected links to find a shortest path to the  
24 specified destination if the intra-area indication is included in the referenced  
25 entry, or performing the shortest path calculation on the selected links to find

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1 a shortest path tree in the identified area and determining a route from the  
2 shortest path tree.

3 According to a sixth aspect, the present invention provides a routing  
4 method for a hierarchical communication network which is divided into a  
5 plurality of areas in each of which a plurality of routers are interconnected by  
6 links, the routers of neighboring areas being interconnected by at least one  
7 area border router, wherein each of the routers functions as a source router  
8 when a request signal is received and includes a first table having a plurality  
9 of entries respectively corresponding to reachable destinations, each of the  
10 entries including an intra-area or an inter-area indication, an area identifier  
11 identifying at least one traversable area, and a list of area border routers if the  
12 inter-area indication is included, and a plurality of second tables respectively  
13 corresponding to the areas, each of the second tables holding quality-of-  
14 service (QoS) values of the links of the corresponding area. The routing  
15 method comprises the steps of receiving, at the source router, a request signal  
16 specifying a destination and a QoS value, for making reference to one of the  
17 entries of the first table and one of the second tables corresponding to the  
18 specified destination, selecting links of the area identified by the area  
19 identifier of the referenced entry which links satisfy the specified QoS value,  
20 and performing a calculation according to a shortest path finding algorithm  
21 on the selected links to find a shortest path to the specified destination if the  
22 intra-area indication is included in the referenced entry, or performing the  
23 shortest path calculation on the selected links until a shortest path tree is  
24 found for all routers of the list of the referenced entry or until an end of the  
25 calculation is reached when the tree is not found for all the routers if the

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1 inter-area indication is included in the referenced entry, and determining  
2 from the shortest path tree a route having an optimum QoS value.

3 Due to the listing of the area ID in the first table, the path finding  
4 calculation for intra-area destinations is limited only to the local area.  
5 Wasteful calculations on unnecessary links for other areas are eliminated.

6 Further, due to the listing of at least one traversable area ID and the  
7 router ID's of corresponding area border routers in the first table, the path  
8 finding calculation for inter-area destinations is limited only to the  
9 traversable area. Wasteful calculations on unnecessary links for other areas  
10 are eliminated. In addition, the amount of shortest path tree calculations is  
11 minimized due to the fact that the calculation is performed until a QoS  
12 shortest path tree is found for all area border routers of the traversable area or  
13 until it terminates of its own accord when such a path is not found for all area  
14 border routers.

#### 15 BRIEF DESCRIPTION OF THE DRAWINGS

16 The present invention will be described in detail further with reference  
17 to the following drawings, in which:

18 Fig. 1 is a block diagram of an exemplary hierarchical communication  
19 network of the present invention;

20 Fig. 2 is a block diagram of a representative router of the network of  
21 Fig. 1;

22 Figs. 3A, 3B and 3C are illustrations of resource tables of the  
23 representative router; and

24 Figs. 4A and 4B are flowcharts of the operation of the processor of Fig.  
25 2 according to the present invention.

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DETAILED DESCRIPTION

1  
2 In Fig. 1 an IP (Internet Protocol) network is illustrated in simplified  
3 form in which routing is performed based on a user-requested QoS (quality  
4 of service) value in accordance with the present invention. As a typical  
5 example, the QOSPF (QoS extended Open Shortest Path First) algorithm will  
6 be explained. The IP network 1 is comprised of a hierarchical QOSPF  
7 network 2 and an autonomous system 3. The QOSPF network 2, which is  
8 also an autonomous system in the IP network, is formed by three OSPF areas  
9 4, 5 and 6, with the area 5 being a backbone area that functions as a core of  
10 the QOSPF network. In each of these areas, routers are interconnected as  
11 neighbors sharing the same Area identifier (ID) and the routers on the border  
12 of two adjacent areas operate as Area Border Routers (ABR). As illustrated,  
13 the area 4 is comprised of routers 41 to 45, with the routers 44 and 45 being  
14 ABRs connected to routers 51, 52 of the backbone area 5 and the router 41  
15 being connected to a network 40 as a neighbor of the area 4. Area 6 is  
16 comprised of routers 61 to 65, with the routers 61 and 62 being ABRs  
17 connected to routers 52, 53 of the backbone area 5 and the router 65 being  
18 connected to a network 60 as a neighbor of the area 6. Routers 42 and 51 are  
19 autonomous system border routers (ASBRs) for the autonomous system 3.  
20 Within the OSPF network, the routers send routing updates with the use of  
21 link-state advertisement packets, or LSAs such as router LSA, network LSA,  
22 summary LSA and AS-external LSA.

23 Each of the area border routers 44 and 45 shrinks the routing updates  
24 of their local area 4 into a summary and sends it to the backbone 5 and  
25 shrinks the routing updates of backbone area 5 into a summary for

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1 distribution within their local area 4. Likewise, each of the area border  
2 routers 61 and 62 shrinks the routing updates of their local area 6 into a  
3 summary for distribution to the backbone area 5 and shrinks the routing  
4 updates of backbone 5 into a summary for distribution within their local area  
5 6. Note that the summary of backbone 5 distributed within the area 4 also  
6 contains the summary of area 6. Hence all routers of area 4 have the  
7 knowledge of which destinations are reachable within area 6 as well as  
8 within the backbone area 5. Likewise, all routers of area 6 have the  
9 knowledge of which destinations are reachable within areas 4 as well as  
10 within the backbone area 6.

11 As shown in Fig. 2, each of the routers of the present invention  
12 includes an interface 20 connected via communication links to neighboring  
13 routers. The interface 20 performs routing with the neighbors according to  
14 the routing protocol of the OSPF domain. Interface 20 is associated with a  
15 topology table 21 and a plurality of resource tables to maintain network  
16 database by exchanging LSAs with neighboring routers. As a representative  
17 router, the router 44 may includes a resource table 22 for holding the  
18 bandwidth database of its local area 4, a resource table 23 for holding the  
19 bandwidth database of the backbone area 5 and a resource table 24 for  
20 holding a summarized database of the non-adjacent area 6. More specifically,  
21 the summarized resource table 24 contains hot count values and remaining  
22 bandwidths of routes from the area border routers 61 and 62 to the network  
23 60.

24 Topology table 21 has a number of entries respectively corresponding  
25 to a plurality of reachable destinations. Each entry is subdivided into a

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1 plurality of fields including an IN/OUT field, an AREA ID field, and an ABR  
2 LIST field. The IN/OUT field indicates whether the destination of the entry  
3 is inside or outside of the local area of the router. The AREA ID field contains  
4 the Area IDs of all areas that can be traversed along routes to the destination.  
5 The ABR LIST field indicates one or more area border routers (ABRs) along  
6 possible routes to the reachable destination.

Router 44, for example, uses LSA packets to create entries for the networks 40 and 60 and the autonomous system 3 in the topology table 21. Specifically, the router 44 examines the router LSA and the network LSA flooded in the local area 4 and recognizes that the network 40 exists within the same area 4 as router 44 and sets an "IN" (intra-area) indication in the IN/OUT field of the first entry of the topology table 21 and sets ID = 4 in the AREA ID field and leaves the ABR LIST field of this entry vacant. Router 44 examines the router LSAs and network LSAs flooded in the areas 4 and 5 and determines that the network 60 is not the same member of the local area 4 and proceeds to examine the summary LSA advertised to the backbone 5 from the routers 61 and 62 and sets an "OUT" (inter-area) indication and ID = 5 in the IN/OUT and AREA ID fields of the second entry and sets Routers 61 and 62 in the ABR LIST field. In the case of the autonomous system 3, the router 44 determines that it is not the same member of the area 4 from the router LSA and network LSA flooded in the local area 4 and the backbone area 5 and proceeds to refer to the AS-external LSAs advertised to the OSPF network 2 and sets an "OUT" indication in the IN/OUT field of the third entry, and ID = 4 and ID = 5 in the AREA ID field, and sets Routers 42 and 51 in the ABR list.

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1 Figs. 3A, 3B and 3C show details of the resource tables 22, 23 and 24.  
2 To create these resource tables, the router 44 uses resource data of active links  
3 of area 4 and stores their usable bandwidths for both outgoing and incoming  
4 links in the resource table 22. In the same manner, the router 44 stores usable  
5 bandwidths of active links of backbone area 5 in the resource table 23. Router  
6 44 is advertised of summarized resource data of active links in the area 6  
7 from the routers 61 and 62 as shown in Fig. 3C.

8 A processor 25, is connected to the tables 20, 21, 22 and 23. As will be  
9 described, the processor 25 is responsive to a request from users to perform  
10 on-demand QoS route calculations using the contents of the topology and  
11 resource tables and replies with a return message containing the result of the  
12 route calculations.

13 The operation of the processor 25 proceeds according to the flowcharts  
14 shown in Figs. 4A and 4B.

15 When an OSPF router receives a request signal from a user for an on-  
16 demand QoS route calculation (step 70), the processor 25 proceeds to step 71  
17 to make reference to an entry of the topology table 21 that corresponds to a  
18 destination specified in the request signal and reads the IN/OUT field to  
19 determine whether the specified destination is inside or outside of the local  
20 area of the source router.

21 At step 72, the processor reads the Area ID of the referenced entry of  
22 the topology table. At step 73, the processor makes reference to one of the  
23 resource tables that corresponds to the area identified by the read Area ID  
24 and reads resource and routing data. At step 74, the processor 25 uses the  
25 read routing data to select links whose bandwidths satisfy a value specified

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1 in the request signal.

2 At step 75, the processor 25 performs calculations according to the  
3 Dijkstra algorithm on the selected links to find a QoS shortest path to the  
4 specified destination. If a shortest path is not found (step 76), a reply  
5 message is sent to the requesting user to inform that the destination is  
6 unreachable. If the decision is affirmative at step 76, the processor proceeds  
7 to step 77 to inform the user of the routing information of the calculated  
8 shortest path.

9 If the destination specified in the request signal is outside of the local  
10 area, flow proceeds from step 71 to step 80 (Fig. 4B) to read the Area ID of the  
11 referenced entry of the topology table. Processor 25 then makes reference to  
12 one of the resource tables that corresponds to the read Area ID (step 81), and  
13 uses the read routing data to select links whose bandwidths satisfy the user-  
14 specified value (step 82). At step 83, the processor reads all Router ID's of the  
15 ABR list of the referenced entry of the topology table.

16 At step 84, the processor 25 performs calculations according to the  
17 Dijkstra algorithm on the selected links to find a QoS shortest path tree to all  
18 routers of the ABR list. If a shortest path tree is found for all routers of the  
19 ABR list (step 85), the processor terminates the calculation at step 86 and  
20 proceeds to step 87. If a shortest path tree is not found for all routers the ABR  
21 list, the processor proceeds from step 85 to step 88 to check to see if the  
22 calculation has terminated. If not, flow returns to step 84 to continue the  
23 calculation. Therefore, if the decision at step 88 is affirmative it can be  
24 determined that a shortest path tree has not been found for any router of the  
25 ABR list or one has been found for some of the routers of the ABR list.

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1       At step 87, the processor determines whether the above process has  
2       been performed on all traversable areas identified by the Area ID's of the  
3       referenced entry of the topology table. If not, flow returns to step 80 to read  
4       the next Area ID from the referenced entry and repeats until the shortest path  
5       finding calculation is performed on QoS-satisfying links of all traversable  
6       areas indicated in the referenced entry of the topology table.

7        Decision step 89 determines whether at least one shortest path tree has  
8        been found. If the decision is affirmative, the processor selects a route with a  
9        maximum remaining bandwidth from the shortest path tree (step 90) and  
10       informs the requesting user of the selected route (step 91). Otherwise, the  
11       processor sends a message indicating that the destination is unreachable.

Assume that the processor 25 of router 44 receives an on-demand QoS route calculation request from a user, requesting a 10-Mbps route and specifying the network 40 as a destination (step 70). Processor 25 first looks up the topology table 21 and determines that the destination is in the same local area (step 71). In the topology table 21, the entry of network 40 is referenced for reading the intra-area indication and the Area ID = 4 (step 72) and the resource table 22 is referenced corresponding to the Area ID = 4 (step 73) for reading the resource and routing data of the local area 4. Links of the area 4 whose remaining bandwidths satisfy the requested 10 Mbps are selected (step 74). Thus, the 5-Mbps outgoing link from router 42 to router 41 is excluded in the link selection process and the processor performs Dijkstra algorithm path finding calculation (step 75) on the selected links to find a route 100 as a shortest path to the destination (see Fig. 1), including the first link from router 44 to router 42, the intermediate link from router 42 to router

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1 43 and the final link from router 43 to router 41.

2 Thus, due to the listing of the area ID in the topology table, the path  
3 finding calculation for intra-area destinations is limited only to the local area.  
4 Wasteful calculations on unnecessary links for other areas are eliminated.

5 If the user requests a 15-Mbps route to the network 60 (step 70).  
6 Processor 25 determines that the destination is outside of the local area (step  
7 71). Processor 25 then examines the Area-ID field of the entry and knows that  
8 the backbone area 5 is the traversable area and the network 60 can be reached  
9 via the backbone area 5. In the topology table, the entry of network 60 is  
10 referenced and the Area ID = 5 of the backbone area 5 is read (step 80).  
11 Processor 25 knows that the network 60 can be reached via links of the  
12 backbone area 5 to the routers 61 and 62. corresponding to Area ID = 5, the  
13 resource table 23 is referenced (step 81) and links of remaining bandwidth of  
14 at least 15-Mbps are selected from this resource table (step 82). Processor 25  
15 reads the router identifiers ID = 61 and ID = 62 of the ABR list of the  
16 referenced entry (step 83). Processor 25 performs the Dijkstra algorithm  
17 calculation on the selected links to find a shortest path tree that extends from  
18 the source router 44 to the area border routers 61 and 62 (steps 84 to 87). For  
19 example, two routes 101 and 102 from the router 44 to area border routers 61  
20 and 62 are selected. Route 101 includes a first link from router 44 to router  
21 51, an intermediate link from router 51 to router 53, an intermediate link from  
22 router 53 to router 52 and a final link from router 52 to router 61. Second  
23 route 102 includes a first link from router 44 to router 51, an intermediate link  
24 from router 51 to router 53 and a final link from router 53 to router 62. Since  
25 there is only one Area ID in the entry of the network 60, the processor then

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1 proceeds from step 87 to step 89. Since two routes are determined, the  
2 processor examines the summarized resource table 24 and compares the two  
3 selected routes in terms of bandwidth available to the network 60 in the area  
4 6 or hop count values of routes from the source router 44 to the area border  
5 routers 61 and 62.

6 Thus, due to the listing of at least one traversable area ID and the  
7 router ID's of corresponding area border routers in the topology table, the  
8 path finding calculation for inter-area destinations is limited only to the  
9 traversable area. Wasteful calculations on unnecessary links for other areas  
10 are eliminated. Further, the amount of shortest path tree calculations is  
11 minimized due to the fact that the calculation is performed until a shortest  
12 path tree is found for all area border routers of the traversable area or until it  
13 terminates of its own accord when such a path is not found for all area border  
14 routers.

15 If the policy of the OSPF network places priority on bandwidth, the  
16 processor makes a decision in favor of the route from the router 61 to the  
17 destination because of its greater remaining bandwidth than the route from  
18 router 62 to the same destination. Therefore, the requesting user is informed  
19 of the route 101 as a best route. If the routes 101 and 102 have different  
20 values of minimum bandwidth, the larger of these will also be taken into  
21 account in the final process of route selection along with the bandwidths  
22 available in the area 6.

23 If the policy of the OSPF network places priority on hop count value,  
24 the processor produces a first sum of the hop count of route 101 plus the hop  
25 count of the route from router 61 to the destination and a second sum of the

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- 1 hop count of route 102 plus the hop count of the route from router 62 to the  
2 destination. Since the first sum equals 7 ( $= 4 + 3$ ) and the second sum equals  
3 6 ( $= 3 + 3$ ), the processor makes a decision in favor of route 102 because of its  
4 smaller total value of hop count to the network 60.